US-PAT-NO: 5907792

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TITLE: Method of forming a **silicon nitride** layer

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Abstract Text - ABTX (1):

A method of forming a **silicon nitride** layer or film on a semiconductor wafer structure includes forming a **silicon nitride** layer on the surface of a wafer structure using a molecular beam of high purity elemental Si and an atomic beam of high purity nitrogen. In a preferred embodiment, a III-V compound semiconductor wafer structure is heated in an ultra high vacuum system to a temperature below the decomposition temperature of said compound semiconductor wafer structure and a **silicon nitride** layer is formed using a molecular beam of Si provided by either thermal evaporation or **electron beam** evaporation, and an atomic nitrogen beam provided by either RF or microwave plasma discharge.

TITLE - TI (1):

Method of forming a **silicon nitride** layer

Brief Summary Text - BSTX (2):

The present invention pertains to methods of forming a **silicon nitride** layer on a supporting structure and more particularly to methods of forming a **silicon nitride** layer by a molecular/atomic beam technique in an ultra high vacuum.

Brief Summary Text - BSTX (5):

In prior art, insulating **silicon nitride** layers or films are routinely fabricated on Si substrate using chemical vapor deposition (CVD) techniques with silane (or dichlorosilane) and ammonia as source materials. The substrate is typically held at temperatures in excess of 700.degree. C. for **silicon nitride** deposition to allow efficient cracking of the silane gas.

applications.

Brief Summary Text - BSTX (18):
It is yet a further purpose of the present invention to provide a new and improved method of fabricating a **silicon nitride** layer or film wherein the substrate deposition temperature is below the decomposition temperature of the compound semiconductor wafer structure.

Brief Summary Text - BSTX (19):
It is still a further purpose of the present invention to provide a new and improved method of fabricating a **silicon nitride** layer wherein the **silicon nitride** layer is fabricated on a stoichiometric upper surface of a compound semiconductor wafer structure.

Brief Summary Text - BSTX (21):
It is still a further purpose of the present invention to provide a new and improved method of fabricating a **silicon nitride** layer or film on semiconductor wafer structure which is relatively easy to fabricate and use.

Brief Summary Text - BSTX (23):
The above problems and others are at least partially solved and the above purposes and others are realized in a method of forming a **silicon nitride** layer or film on a semiconductor wafer structure including the steps of providing a semiconductor wafer structure with a surface and forming a **silicon nitride** layer on the surface of the wafer structure using a molecular beam of high purity elemental Si and an atomic beam of high purity nitrogen.

Brief Summary Text - BSTX (24):
In a preferred embodiment, a III-V compound semiconductor wafer structure is heated in an ultra high vacuum system to a temperature below the decomposition temperature of said compound semiconductor wafer structure and a **silicon nitride** layer is formed using a molecular beam of Si provided by any one of thermal evaporation and **electron beam** evaporation, and an atomic

nitrogen beam
provided by any one of RF or microwave plasma discharge.

Drawing Description Text - DRTX (3):

FIG. 1 is a simplified cross-sectional view of a compound semiconductor wafer structure with a **silicon nitride** layer in accordance with the present invention; and

Detailed Description Text - DETX (2):

Referring specifically to FIG. 1, a simplified cross-sectional view of a semiconductor wafer structure 10 with a **silicon nitride** layer in accordance with the present invention is illustrated. Structure 10 includes a semiconductor material, such as any material employed in any semiconductor device, represented herein by a semiconductor substrate 11 and a layer structure 12. For purposes of this disclosure, the substrate, any epitaxial layers, and any amorphous layers formed thereon will be referred to simply as a semiconductor wafer structure which in FIG. 1 is designated 13. Semiconductor wafer structure 13 has an upper surface 15 onto which a **silicon nitride** layer 14 is positioned using a molecular/atomic beam technique. It will of course be understood that in some specific applications (or on some portions of compound semiconductor wafer structure 13) there may be no epitaxial layers and/or no amorphous layers present and upper surface 15 may simply be the upper surface of the substrate 11.

Detailed Description Text - DETX (4):

In a specific embodiment, a compound semiconductor wafer structure 13 with an upper surface 15 is mounted onto substrate holder 25 and loaded into UHV chamber 21. The upper surface 15 of semiconductor wafer structure 13 may be provided by an epitaxial layer or an amorphous oxide film which gives low interface state density D.sub.it on GaAs based semiconductors. Subsequently, compound semiconductor wafer structure 13 is heated to a substrate

deposition temperature below the decomposition temperature of said semiconductor wafer structure. A molecular beam of Si 26 is generated thermally using Knudsen cell 22, and an atomic beam of nitrogen 27 is provided by a commercially available RF plasma source 23. After opening the shutters 24, silicon beam 26 and nitrogen atomic beam 27 arrive on upper surface 15 of compound semiconductor wafer structure 13. Because the species arriving on the upper surface 15 of compound semiconductor wafer structure 13 are constituent atoms, no cracking is required as is the case of the CVD process. As a result the substrate deposition temperature could be as low as room temperature. Consequently, for **silicon nitride** deposition on a compound semiconductor wafer structure, a stoichiometric surface can be maintained at the start of **silicon nitride** deposition. A stoichiometer upper surface 15 of a compound semiconductor wafer structure 13 can also be more readily accomplished in an MBE system since the compound semiconductor epitaxial layers can be grown and the **silicon nitride** film can be subsequently deposited on the as-grown semiconductor surface 15 without having a problem of surface contamination which occurs when the upper surface 15 of compound semiconductor wafer structure 15 is exposed to atmosphere.

Detailed Description Text - DETX (5):

Another advantage of **silicon nitride** deposition according to the present invention is the absence of hydrogen which provides **silicon nitride** films with significantly **reduced hydrogen** level and consequently, lower trap density N.sub.t. A further advantage of the proposed process is the elimination of ammonia and silane. Ammonia is very corrosive to such things as copper, nickel and viton o-ring seals. Silane on the other hand is highly explosive. Elimination of these gases is desirable in terms of cost for safety

equipment and having to satisfy federal and local authorities for using such gases.

Detailed Description Text - DETX (6):

Thus, a new and improved method of manufacturing a **silicon nitride** layer on a semiconductor wafer structure using a molecular/atomic beam technique is disclosed. The new and improved method of manufacturing a **silicon nitride** layer or film is compatible with a low temperature process and provides **silicon nitride** with a significantly reduced level of hydrogen, and a low trap density. Further, the new and improved method of manufacturing a **silicon nitride** layer is compatible with the requirements of compound semiconductor manufacturing such as compound semiconductor growth and surface preparation schemes applied to gate insulator and surface passivation applications. These improvements essentially solve or overcome the problems of prior art such as dc instability and poor reliability of **silicon nitride**-semiconductor structures.

Claims Text - CLTX (1):

1. A method of forming a **silicon nitride** layer on a semiconductor wafer structure comprising the steps of:

Claims Text - CLTX (3):

forming a **silicon nitride** layer on the surface of semiconductor wafer structure by depositing **silicon nitride** onto the wafer structure using a combination molecular beam and atomic beam technique to provide constituent atoms at the surface.

Claims Text - CLTX (4):

2. A method of forming a **silicon nitride** layer on a semiconductor wafer structure as claimed in claim 1 wherein the **silicon nitride** layer is formed using a molecular beam of elemental Si and an atomic beam of nitrogen.

Claims Text - CLTX (5):

3. A method of forming a **silicon nitride** layer on a semiconductor
wafer
structure as claimed in claim 1 wherein the step of providing a
semiconductor
wafer structure includes providing a structure with a compound
semiconductor
material having a decomposition temperature and the step of forming a
silicon
nitride layer is is performed at a temperature below the
decomposition
temperature of the compound semiconductor material.

Claims Text - CLTX (6):
4. A method of forming a **silicon nitride** layer on a semiconductor
wafer
structure as claimed in claim 1 wherein the step of forming the
silicon nitride
layer includes the formation of a **silicon nitride** layer with a
reduced level of
hydrogen.

Claims Text - CLTX (7):
5. A method of forming a **silicon nitride** layer on a semiconductor
wafer
structure as claimed in claim 1 wherein the step of forming the
silicon nitride
layer includes the formation of a **silicon nitride** layer with a low
trap density
<10.sup.11 cm.sup.-2.

Claims Text - CLTX (8):
6. A method of forming a **silicon nitride** layer on a semiconductor
wafer
structure as claimed in claim 1 wherein the step of providing the
semiconductor
wafer structure includes providing a semiconductor wafer with a
semiconductor
device or a semiconductor device structure formed thereon.

Claims Text - CLTX (9):
7. A method of forming a **silicon nitride** layer on a compound
semiconductor
wafer structure comprising the steps of:

Claims Text - CLTX (11):
forming a **silicon nitride** layer on the surface of compound
semiconductor
wafer structure by depositing **silicon nitride** onto the wafer
structure using a
combination molecular beam and atomic beam technique to provide

constituent
atoms at the surface.

Claims Text - CLTX (12):
8. A method of forming a **silicon nitride** layer on a compound semiconductor
wafer structure as claimed in claim 7 wherein the step of providing a compound
semiconductor wafer structure includes providing a semiconductor wafer of GaAs.

Claims Text - CLTX (13):
9. A method of forming a **silicon nitride** layer on a compound semiconductor
wafer structure as claimed in claim 7 wherein the step of providing a compound
semiconductor wafer structure includes the growth of epitaxial compound
semiconductor layers on the surface of a compound semiconductor wafer.

Claims Text - CLTX (14):
10. A method of forming a **silicon nitride** layer on a compound semiconductor
wafer structure as claimed in claim 7 wherein the step of providing a compound
semiconductor wafer structure includes the deposition of an amorphous layer on
the surface of a compound semiconductor wafer structure.

Claims Text - CLTX (15):
11. A method of forming a **silicon nitride** layer or film on a compound
semiconductor wafer structure as claimed in claim 7 wherein the step of forming
a **silicon nitride** layer is compatible with the requirements of III-V compound
semiconductors manufacturing.

Claims Text - CLTX (16):
12. A method of forming a **silicon nitride** layer or film on a compound
semiconductor wafer structure as claimed in claim 7 wherein the step of forming
a **silicon nitride** layer is compatible with the UHV temperature and pressure
requirements of compound semiconductor growth and surface preparation schemes
applied to gate insulator and surface passivation applications.

Claims Text - CLTX (17):
13. A method of forming a **silicon nitride** layer or film on a compound
semiconductor wafer structure as claimed in claim 7 wherein the compound
semiconductor wafer structure has a decomposition temperature and the substrate
deposition temperature is below the decomposition temperature of the compound
semiconductor wafer structure.

Claims Text - CLTX (18):
14. A method of forming a **silicon nitride** layer or film on a compound
semiconductor wafer structure as claimed in claim 7 wherein the step of forming
the **silicon nitride** layer includes the formation of a **silicon nitride** layer
fabricated on a stoichiometric upper surface of a compound semiconductor wafer
structure.